Climate Change Impact on Flow Discharge of Kunhar River Catchment using Snowmelt Runoff Model

Syed Shahid Ali* and Sayed Sanaullah Shah*

Department of Geography, University of Karachi, Karachi, Pakistan

Abstract: Most of the runoff in Kunhar Catchment is generated from the snowmelt which makes it more sensitive to climate change. The Snowmelt-Runoff Model (SRM), a simple degree-day model, has been applied around the world under different climatic regions to evaluate the hydrological effects of climate change.

The current study encompasses the use of Snowmelt-Runoff Model (SRM) to forecast stream flows in Kunhar river catchment depicting three varying climate change scenarios i.e. a) an increase in +2°C temperature b) an increase in +2°C temperature along with 20% increase in precipitation, and c) a 20% increase in precipitation. The study area was distributed with respect to varying altitude with 500 m elevation interval. Moderate resolution Imaging Satellite (MODIS) daily snow product MOD10A1 is used to map snow cover. SRM model was simulated and later climate change run was evaluated. SRM Model was calibrated for 2003 – 2004 and validated for 2005 – 2006 with an average coefficient of 0.93 R^2 and average seasonal volume difference D_v of 1.46%. The stimulated results for scenario “b” show an increase of flow discharge by 27%. Whereas, there was 21% and 6% increment in discharge simulated for scenarios “a” and “c” respectively.

Keywords: SRM, Climate Change, Remote Sensing, Hydrology.

I. INTRODUCTION

Pakistan is facing scarcity of water for many decades for its larger parts and the situation is expected to worsen with other environmental challenges including global warming and lack of water management concerns. The flow discharges coincide with the summer and wet seasons which dramatically amplify the flooding of lower Indus basin under the impact of climate change; especially in Sindh province Akhter *et al*. [1]. Hence, monitoring of northern catchments which are the major sources of runoff from cryosphere melt is impulsive to stimulate the yearly runoff into rivers. Moreover, monitoring and supervising the climatic change impacts on water resources is also imperative for scheduling and implementation of hydrological structures Tahir *et al*. [2]. Study by Akhter *et al*. [1], indicates dramatic increase in the precipitation and mean annual temperature by the end of 21st century up to 16% and 4.8ºC respectively. Also, Panday [2], have given three hypothetical scenarios for future climatic changes i-e a) +4 ºC and 20% increase in temperature and precipitation respectively, b) +4 ºC increase in temperature, c) 20% increase in precipitation. SRM model was used to assess the impacts of climatic change under these scenarios. An extensive use of computer simulation models are performed to project availability / scarcity of future water under diverse conditions of climate. These models are used to project the future runoff situation over a long-term by taking into account previous climatic data.

Overall, the Snowmelt-Runoff Model is a capable technique to forecast and simulate runoffs from catchment; especially in catchments, snowmelt is the major contributor to runoff [3, 4].

II. METHODOLOGY

Methodology of the study consists of three major steps. Data Acquisition and Data Pre-Processing, Simulation of SRM Model and Climate change run using SRM Model. The data of study area, the Neelum River catchment was acquired, processed and put into SRM model for model simulation.

Simulation of catchment for the Kunhar River for 4 years (2003-2006) and evaluation of climate change impacts on the future flow discharge was the fundamental endeavor of the current study. Calibration of the SRM model for the years 2003-2004 was performed which was then validated for the years 2005-2006. Impact of climatic change is evaluated by defining three different climate change scenarios. Snow cover product MOD10A1 from MODIS is used to map snow cover and spatially distributed NOAA precipitation tiles are used as the precipitation data source.

Study area is shown in Figure **1** and detailed methodology flow diagram is shown in Figure **2**.

A. Study Area

The Kunhar River originates from Lulusar Lake and is fed by snow and glacial melt from high altitude

*Address correspondence to these authors at the Department of Geography, University of Karachi, Karachi, Pakistan; E-mails: shahidgeog@gmail.com, sanaullahbukhari@gmail.com

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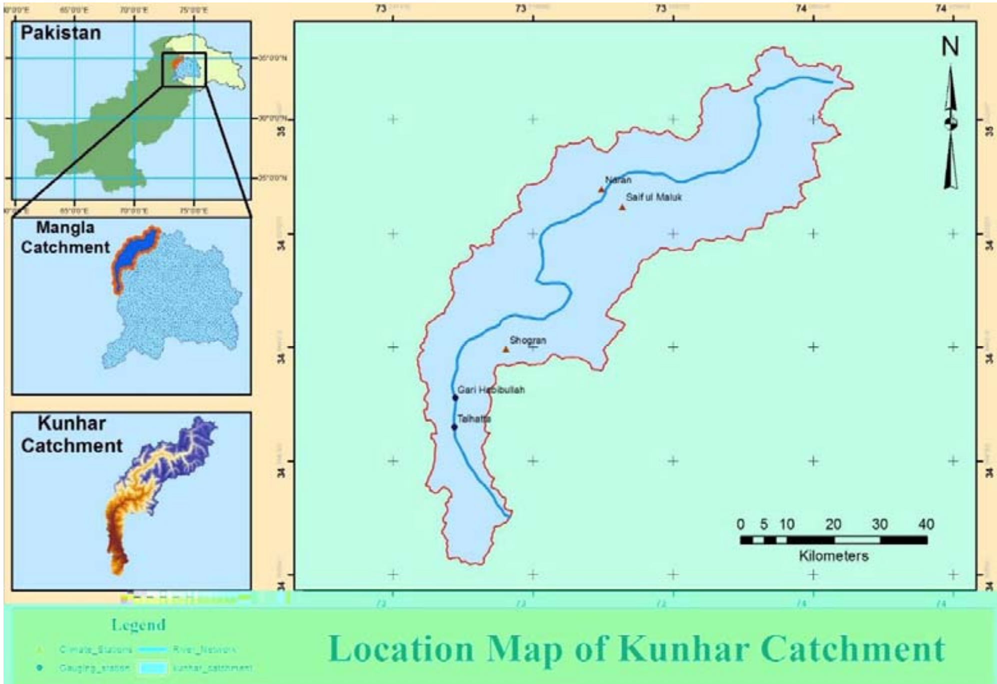

Figure 1: Location map of the study area.

mountains like Malka Parbat. The river is also fed by Saiful Muluk and Dudipatsar.

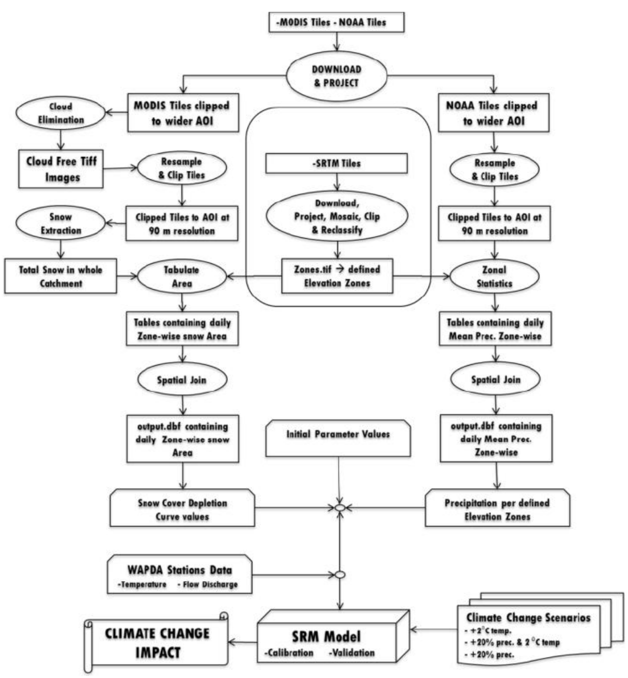

Figure 2: Methodology flow diagram.

B. Data Acquisition and Data Pre-Processing

1. Basin Characteristics

DEM from Shuttle Radar Topography Mission (SRTM) was downloaded from http://www.srtm.csi.cgiar.org/. ERDAS Imagine was used to develop mosaic of the downloaded tiles. Mosaic of the tiles was then clipped to the study area. 500 m interval was used to classify clipped area into elevation zones using ArcGIS.

Figure 3: An illustration of cloud elimination technique.

The area of a zone with equal elevation areas above and below is called the Hypsometric Mean Elevation of that area. Calculation of total area for each elevation was performed by exporting the values of attribute table from clipped area into Excel. A graph was plotted between the derived hypsometric mean elevations for each zone and cumulative area. Hypsometric mean elevation of each zone is put into SRM model. However these curves are not shown in this paper.

2. Model Variables

There are three model inputs or variables namely temperature, precipitation and snow covered area (SCA).

a. Snow Covered Area (SCA)

The most important input for SRM and Cold Regions Hydrological Model (CRHM) is the snow covered area [5]. Mapping of snow covered areas can be performed by using terrestrial observations for small basins or by using aerial and satellite imagery for large basins. However, owing to landscape and avalanches; direct measurements are often not feasible for snow cover mapping [6].

R programming was used to download and project MOD10A1 product from MODIS. Batch processing in ArcGIS was used to clip MODIS daily snow tiles to the study area using “Extract By Mask” tool in Spatial Analyst toolset. “Extract By Attribute” tool was used to extract snow covered area through batch processing from all the clipped tiles. The value of snow in classified MOD10A1 product is 200 which was used for the extraction. “Tabulate Area” tool is used to batch calculate snow covered area per defined elevation zones. Output of tabulate area tool is a table having a column stating the number of elevation zone and another column showing snow covered area in square meters. A python script is used to transpose and add date to each of these output tables. All transposed tables are then joined together using “Append” tool. The joined table thus obtained contains the snow covered area for each day with cloud cover within the acceptable percentage. This table was exported into MS Excel and snow covered area for each zone of all the available days was divided by the total area of the zone. Snow covered area ratio obtained after dividing was plotted to get conventional depletion curves (CDC’s) for each year. Snow covered area ratio for all the missing days and for each zone was obtained from the graph.

b. Precipitation

Methodology adopted to calculate SCDC was modified a little to calculate daily mean precipitation zone-wise. Downloaded, projected, resampled at 500 m and clipped to wider area of interest daily precipitation tiles of NOAA were further clipped to the study area using extract by mask tool. “Zonal Statistics as Table” tool in ArcGIS was used to calculate daily mean precipitation zone-wise. Python script tool was developed and used to transpose the table of each day and date is added to each table. Append tool was used to join tables containing daily mean precipitation zone-wise

C. Simulation of SRM Model

Calculated CDC values, temperature data acquired from Srinagar GHCN climate station and basin characteristics derived from DEM are put in SRM model separately for each year from 2003-2006. Model was calibrated for 2003 and 2004 by tuning the parameters. Parameters of each of these two years were averaged and a little modified to come to a general set of parameters. This generalized set of parameters represents a general trend of how parameters change during a normal year.

This generalized set of parameters was put into model and model was validated for years 2005 and 2006.

D. Climate Change Run Using SRM Model

Three hypothetical climate change scenarios were defined in WinSRM model as listed below.

- Scenario-A → +2 ˚CC
- Scenario-B → +2 ˚C & 20% increase in precipitation
- Scenario-C → 20% increase in precipitation

Climate change impact under these scenarios is evaluated using simulation (validation) of year 2006 as the present climate.

III. RESULTS AND DISCUSSION

A. SRM Model Calibration

From snow cover depletion curves, it is evident that snow started melting in Zone#2-6 from early March. Most of the snow melt occurred till mid of August and from then onwards snow started accumulating again. July experienced highest temperatures of year 2003 in July with maximum temperature as much as 14.9 °C. Temperature remained below the melting point for almost half year. . All of the above mentioned facts are incorporated in parameters tuning for the simulation. Simulated runoff has 0.9531 R^2 and 5.1949% $D_{V.}$ The sudden peak in the runoff after August is caused by rainfall only. Major snowmelt contribution in the runoff is from March to July.

Average precipitation for year 2003 in catchment was 0.23 cm with May bearing highest average precipitation in catchment i.e. 5.98 cm. Average precipitation in successive year of 2004 was reduced to

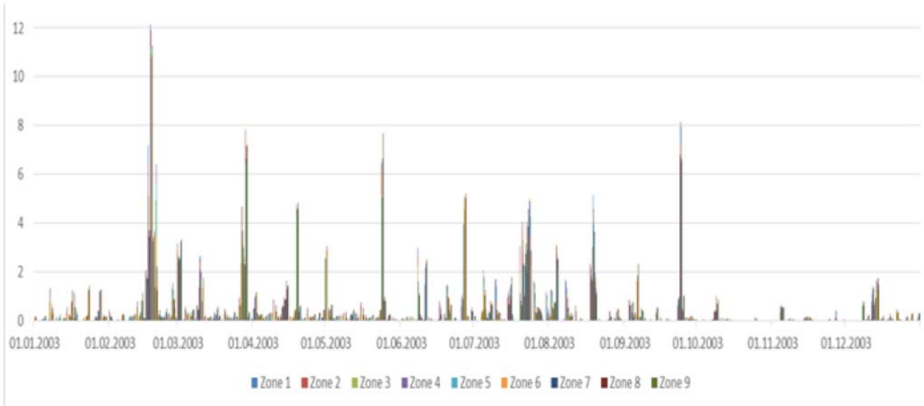

Figure 4: Daily precipitation zone-wise in year 2003.

0.17 cm, with August bearing the highest precipitation i.e. 7.2 cm. Total recorded runoff volume was 3166 million cubic meters for year 2003. Comparatively 2004 observed the total runoff of 2632 million cubic meters. Again all of the above mentioned facts are considered during the adjustment of parameters for 2004. Simulated runoff results for 2004 are 0.926 R^2 and 1.3902% D_v.

Srinagar station lies outside the Neelum River catchment and in the elevation range of 3^{rd} zone. Observing the snow cover depletion curves reveals that snow in third zone started melting in February. So it can be inferred that temperatures as observed by Srinagar station have good correlation with those.

B. SRM Model Validation

Average of tuned parameters in the two calibrated years was calculated through excel. The resultant values of parameters were round off and slightly adjusted so as to get a general set of parameters that is applicable on all years. Once done, these generalized values were validated by their application on next two years 2005 and 2006, while simulating the runoff for individual years. Input variables including precipitation, and SCDC were incorporated into SRM model individually for two years.

Snow melting started in late July for year 2005 while it started in early June for year 2006. June-September

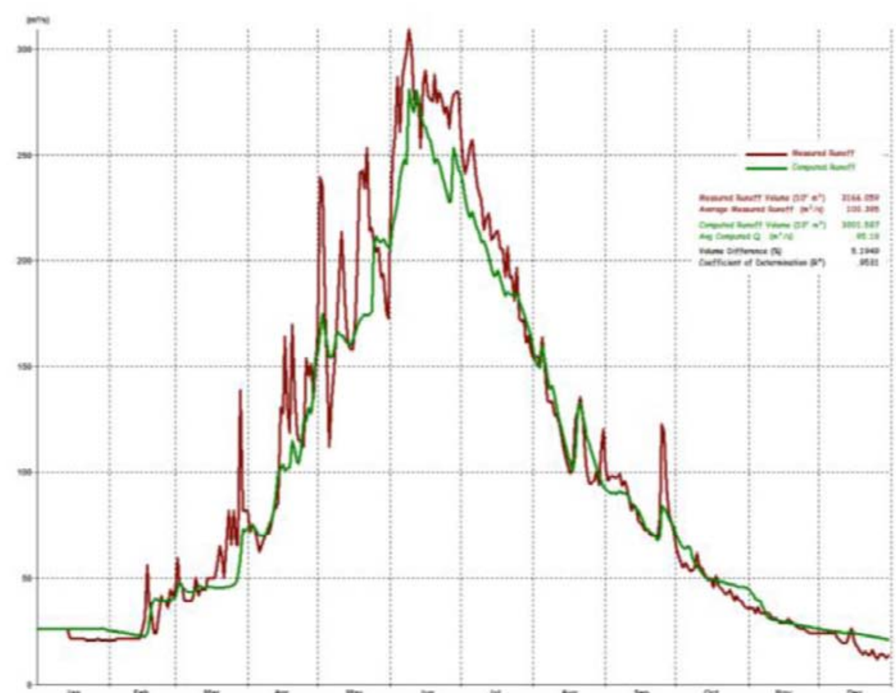

Figure 5: Simulation results for year 2003.

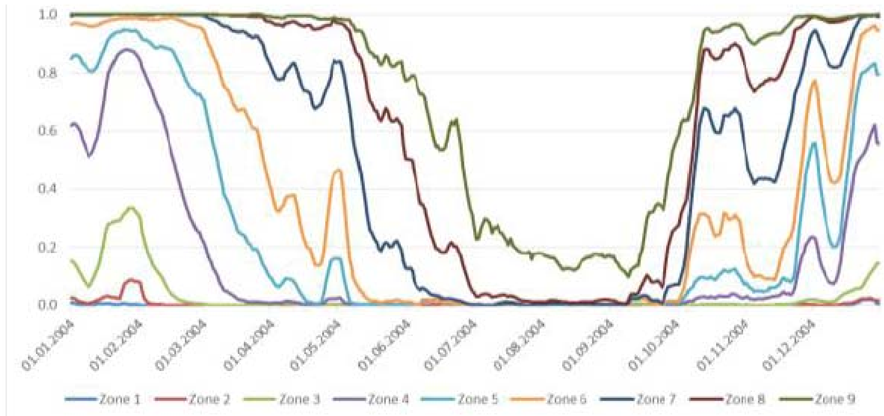

Figure 6: Snow cover depletion curves for year 2004.

Figure 7: Simulation results for year 2004.

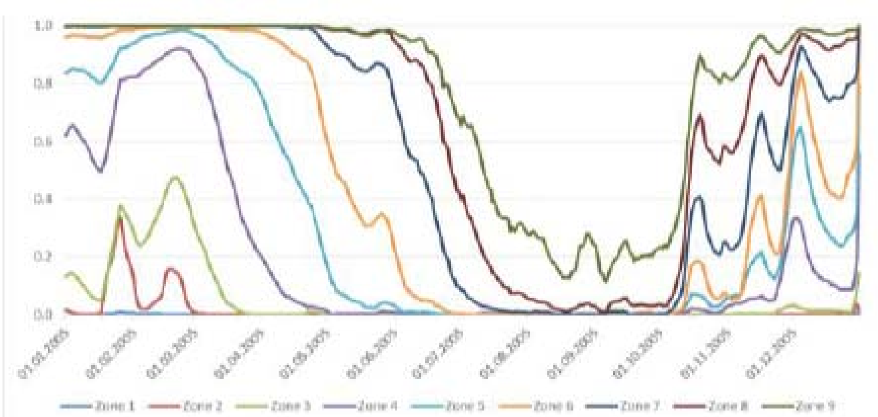

Figure 8: Snow cover depletion curves for year 2005.

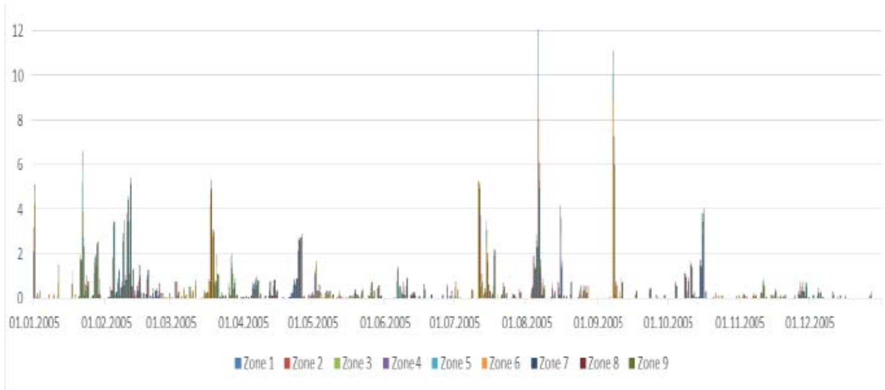

Figure 9: Daily mean precipitation zone-wise for year 2005.

Figure 10: Simulation results for year 2005.

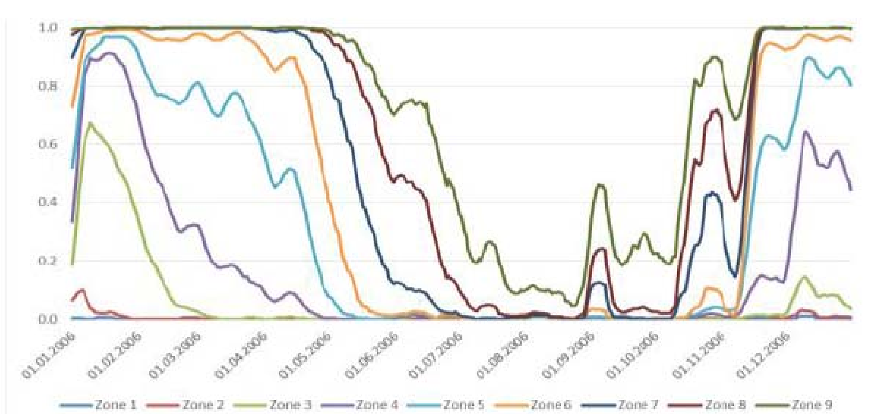

Figure 11: Snow cover depletion curves for year 2006.

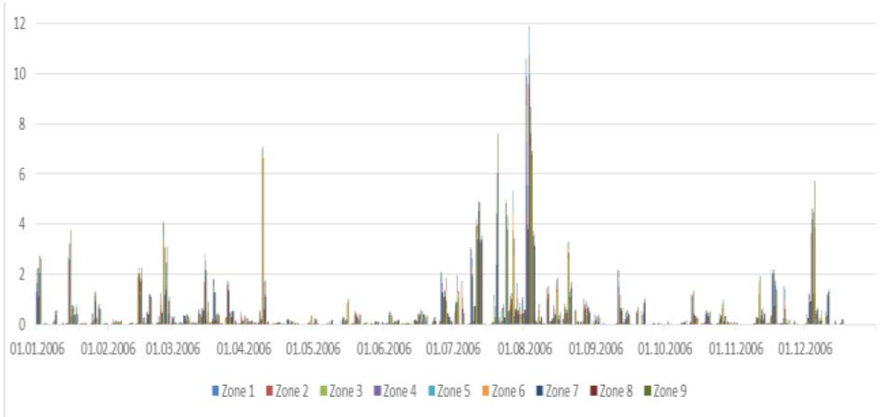

Figure 12: Daily mean precipitation zone-wise for year 2006.

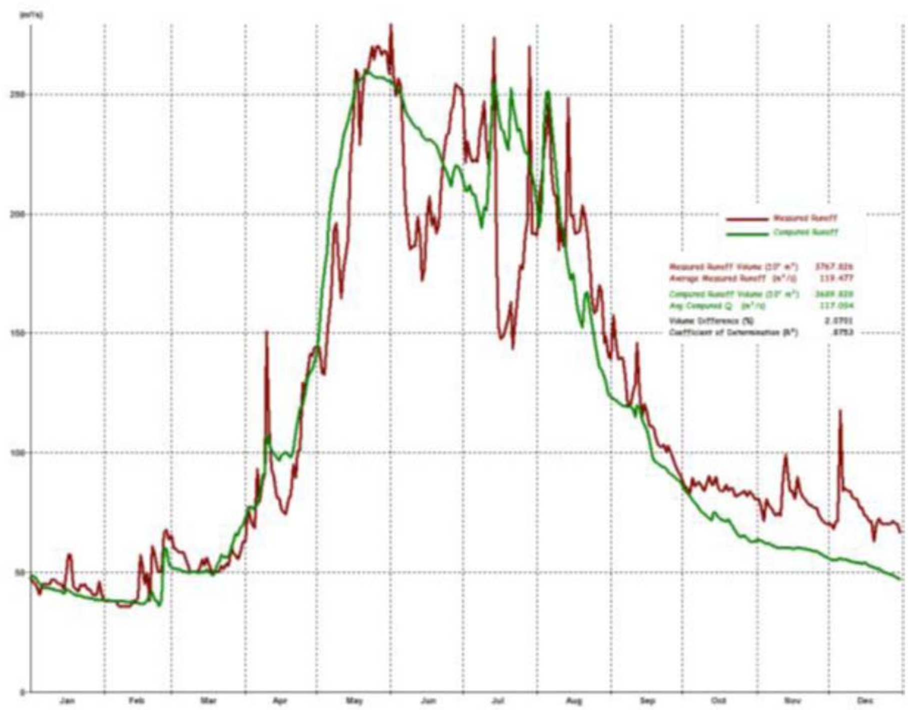

Figure 13: Simulation results for year 2006.

are usually the warmest months in Kunhar Catchment where temperature is about 12° C for these months. Year 2006 had been a bit warmer year where temperature remained close to 15° C as compared to year 2005 where temperature was about 14° C in July.

Catchment received high precipitation in year 2005 as compared to year 2006 with highest precipitation recorded in August for both years. All of the above mentioned data was put into SRM model and the generalized set of parameters was used for model simulation for years 2005 and 2006 separately. Validation of model using this generalized set of parameters yielded 0.9416 R^2 & 4.5386% D_v and 0.8753 R^2 & 2.0701% D_v for years 2005 and 2006 respectively.

Table **1** lists the summary of simulation results. Reference [7] applied SRM model on Astore basin during year 2000. With results yielding 0.91 R^2 and 9.01% D_v

Runoff while calibrating the model from 2003-2005 was simulated in current study with an average 0.939 R^2 and 3.29% D_v. while simulated Runoff for 2005-2006 was found with an average of 0.908 R^2 and 3.304% D_v. The values were found to be in high degree of accuracy with previous studies that were conducted in the same region.

Table 1: Summary of Simulation Results

Year	D_v	R^2
2003	5.1949%	0.9531
2004	1.3902%	0.926 R^2
2005	4.5386%	0.9416
2006	2.0701%	0.8753

IV. CONCLUSIONS AND RECOMMENDATIONS

The efficiency of SRM model is established for the snow fed Kunhar catchment in the study. The study encompasses the calibration of SRM model for two years 2003 & 2004 and is successfully validated for the next two years 2005 & 2006. The average value of R2 was 0.924 and the average value of Dv was 3.29% for all the simulated years, making the results very accurate when compared to previously held studies that have been conducted and mentioned in the SRM's user manual. Here it is worth mentioning that the amount of precipitation received by Kunhar catchment is entirely different for individual years when compared against corresponding months or zones. Hence, calibrating the model for a certain year and simulating it for the years that received same amount of precipitation as the calibrated year can yield better results. Since there are continuous fluctuations in the amount of precipitation received by Kunhar catchment yearly, it is imperious to carry out calibration of SRM model for more than one year to estimate/predict general behavior of the catchment by averaging the parameters of each calibrated year.

Since the SRM model enables definition for simple and complex climatic change scenarios, it is also concluded in the study that SRM is an appropriate model for evaluation of climatic change in Kunhar catchment. Climate is a major contributing factor for the snow fed Kunhar catchment and it is being found that a mere increase of 2^o C temperatures in a given year can increase the runoff in the catchment by 35.5%, while also increasing the precipitation by 20%.

Below listed points can prove to be of crucial guidance for future study endeavors.

- There is a need of locating new data source for remote sensing precipitation data as the current source of NOAA precipitation product (FEWS) cover area from 5˚ N to 35˚ N latitude and from 70˚ E to 110˚ E longitude, while most of glacial fed basins that occur in Pakistan lies at altitude above 35˚ N.
- Though the temperature and precipitation data from GHCN climate stations is reliable, still there are many new stations being formed at higher elevation by ICIMOD, WAPDA, PMD and multiple German and Italian organizations. Latest measurement equipment and gauges are being installed on these new higher elevation stations and one need to identify these data sources to be used in SRM on other basins.
- The daily snow product from MODIS (MOD10A1) has an accuracy of about 93-100%. However its accuracy needs to be evaluated and verified for the present study area.
- An expected increase in discharge i.e. 35.5% under the climate change impact is alarming and demands development of new water reservoirs to cater this increase in discharge.
- organizations with advanced temperature and precipitation measurement equipment's and gauges. Such reliable data sources are needed to be identified for the application of SRM in other basins.
- MODIS daily snow product MOD10A1 is about 93-100% accurate. However this is a global product and its accuracy for the catchment under study needs to be evaluated.
- Cloud elimination technique used in present study is found to be reliable as it avoids snow cover interpolation as much as possible. However its reliability needs to be evaluated further using field measurements.

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